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MTADS Airborne and Vehicular Survey of Target S1 at Isleta Pueblo, Albuquerque, NM, 17 February-2 March 2003

H. H. NELSON

Chemical Dynamics and Diagnostics Branch
Chemistry Division

DAVID WRIGHT
TOM FURUYA
J. R. MCDONALD
NAGI KHADR

AETC, Inc.
Arlington, VA

D. A. STEINHURST

Nova Research Inc.
Alexandria, VA

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6. AUTHOR(S)
H.H. Nelson, David Wright,* Tom Furuya,* J.R. McDonald,* Nagi Khadr,* and D.A. Steinhurst†

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*AETC, Inc., Arlington, VA 22202
†Nova Research Inc., Alexandria, VA 22308
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14. ABSTRACT
In February 2003, the Naval Research Laboratory demonstrated the Multi-sensor Towed Array Detection System (MTADS) vehicular and airborne magnetometer systems on the Pueblo of Isleta, near Albuquerque, NM. The demonstration consisted of two overlapping surveys. First, a vehicular magnetometery survey of 100 acres near the previously identified bull's eye, S1. Targets were expected to be M38 and BDU-33 practice bombs and an array of ordnance emplaced by the Army Engineering R&D Center at the direction of the ESTCP Program Office. Second, an airborne magnetometry survey of ~1500 acres around the target to include the vehicular area. Six hundred ninety targets were selected for remediation by UXO technicians. Each of the remediated items was characterized, photographed, and located by GPS re-survey. Using the results of this remediation, we develop probability of detection statistics for each of the two MTADS systems, derive information about location accuracy, and examine the classification performance of the two systems.

15. SUBJECT TERMS
Multi-sensor Towed Array Detection System (MTADS); Airborne Magnetometry; Unexploded Ordnance (UXO); UXO Detection and Classification

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Abstract

The Chemistry Division of the Naval Research Laboratory has developed the Multi-sensor Towed Array Detection System, MTADS, to address the problem of buried UXO detection and characterization with support from the Environmental Security Technology Certification Program, ESTCP. The original MTADS incorporates both cesium vapor full-field magnetometers and pulsed-induction sensors in linear arrays that are towed over survey sites by an all-terrain vehicle. More recently, man-portable and airborne versions of the system have been demonstrated. Sensor positioning is provided by state-of-the-art Real Time Kinematic (RTK) GPS receivers. The survey data acquired by MTADS are preprocessed using tools from the Geosoft Oasis montaj suite and then targets are analyzed using an NRL-developed Data Analysis System, DAS. The performance of the MTADS has been demonstrated at a number of prepared sites and live ranges over the past five years. The vehicular and man-portable versions can detect and locate ordnance with accuracies on the order of 15 cm while the airborne version has demonstrated location accuracy of 25 – 30 cm.

In February 2003, we demonstrated the vehicular and airborne magnetometer systems on approximately 1550 acres at Target S1 on the Pueblo of Isleta, near Albuquerque NM. This Demonstration had three primary objectives. First, we demonstrated the airborne MTADS in a new geological environment against a new target set. Second, the probability of detection and location accuracy of the airborne system was measured against the baseline vehicular system. The targets for this comparison included the existing practice bombs as well as an emplaced target suite chosen by ESTCP. And, finally, the MTADS airborne system was measured against the system developed and deployed by Oak Ridge National Lab. This intersystem comparison will allow the Institute for Defense Analyses to quantify the performance features of each system.

The Demonstration consisted of three overlapping surveys. First, a vehicular magnetometery survey of 100 acres near the previously-identified bull's eye, S1. Targets on this area were expected to be M38 and BDU-33 practice bombs and an array of ordnance to be emplaced by the Army Engineering R&D Center at the direction of the ESTCP Program Office. Second, an airborne magnetometry survey of 1500 acres around the target to include the vehicular area. Finally, an airborne survey by Oak Ridge National Lab of the same 1500 acres.

The vehicular MTADS system covered 28.1 hectares (69.5 acres) including a 10-m buffer around the vehicular site. In this area, we marked 1364 targets (16 of these were the calibration targets planted in the upper part of the site) for remediation using the now familiar classification scheme of 1 for high-confidence ordnance, 2 for medium-confidence ordnance, 3 for low-confidence ordnance, 4 for low-confidence clutter, 5 for medium-confidence clutter, and 6 for high-confidence clutter. The airborne MTADS system surveyed 570 hectares (1408 acres). Airborne targets were picked in two areas. The first area was the 100-acre vehicular site excluding the densest target area surrounding the bull's eye which resulted in 1260 targets. The second area in which targets were picked was designated the "Primary Area." This area was

chosen by the ESTCP Program Office in conjunction with the two survey teams. Target analysis in this area resulted in 388 targets.

Working from the target lists submitted by each of the three survey teams (MTADS vehicular, MTADS airborne, and ORNL airborne) analysts from the Institute for Defense Analyses, IDA, selected targets for remediation in the two airborne areas mentioned above, the Vehicular Area and the Primary Area. Six hundred ninety (711 original picks - 21 inadvertently included seed targets) targets were selected for remediation by UXO technicians from EOTI, Inc., our remediation contractor. Each of the remediated items was characterized, photographed, and located by GPS re-survey. A number of the targets in the "Primary Area" were reported as "no find" by the EOD teams. Fifty of these targets were re-examined in a follow-up survey by members of the vehicular team in January, 2004.

Using the results of this remediation, we develop probability of detection statistics for each of the two MTADS systems, derive information about location accuracy, and examine the classification performance of the two systems.

MTADS Airborne and Vehicular Survey of Target S1 at Isleta Pueblo

Albuquerque, NM

17 February - 2 March, 2003

1. Introduction

1.1 Background

Buried unexploded ordnance, UXO, is one of the Department of Defense's most pressing environmental problems. Not limited to active ranges and bases, UXO contamination is present at DOD sites that are dormant and in areas adjacent to military ranges that are under the control of other government agencies and the private sector.

Traditional methods for buried UXO detection, characterization, and remediation are labor-intensive, slow and inefficient. Typical detection and characterization methods rely on hand-held detectors operated by UXO technicians who slowly walk across the survey area. This process has been documented as inefficient and marginally effective.[1] In addition, a large portion, approaching 70% in some cases, of the total budget of a typical remediation effort is spent on digging targets that do not turn out to be ordnance.

The Environmental Security Technology Certification Program, ESTCP, has supported the Naval Research Laboratory in the development of the Multi-sensor Towed Array Detection System, MTADS, to address these deficiencies. The MTADS incorporates both cesium vapor full-field magnetometers and pulsed-induction sensors in linear arrays that are towed over survey sites by an all-terrain vehicle. Sensor positioning is provided by state-of-the-art Real Time Kinematic (RTK) GPS receivers. The survey data acquired by MTADS are preprocessed using tools from the Geosoft Oasis montaj suite and then targets are analyzed using an NRL-developed Data Analysis System, DAS. The DAS was designed to locate, identify and categorize all military ordnance at its maximum self-burial depth. It is efficient and simple to operate by relatively untrained personnel. The performance of the MTADS has been demonstrated at a number of prepared sites and live ranges over the past five years.[2-12] It can detect and locate ordnance with accuracies on the order of 15 cm.[5]

Many sites of interest have terrain that cannot be traversed by a vehicle or on foot. Some sites, particularly on active ranges, are cluttered with a variety of ordnance that make clearance or even characterization activities potentially dangerous. Finally, there are many formerly used ranges dating from World War II (and earlier) that are located in areas involving tens or hundreds of

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thousands of acres with isolated bombing targets or impact ranges. Locations of many of these impact areas (or ordnance burial caches) are unknown or imprecisely located. Some of these areas are located on Native American reservations while others involve BRAC or pending BRAC sites.

To address these issues NRL, under ESTCP Project 200031, has developed and demonstrated an airborne adjunct to the MTADS vehicular and man-portable systems. This airborne system allows efficient and effective characterization of many of these areas that are inappropriate for vehicular surveys. It is designed to rapidly, economically, and efficiently survey large sites that are not appropriate for vehicular or man-portable surveys. While the airborne system is not capable of detecting the smallest classes of buried UXO at their maximum likely self-burial depths, it does allow efficient surveys of large areas to locate target bull's eyes, impact clusters, and burial caches. Under favorable conditions we can detect and characterize individual ordnance such as GP bombs and the projectiles larger than 60-mm mortars. For these individual ordnance targets, the system estimates burial depths, likely ordnance size, and provides for target way pointing, as well as creating GIS-compatible target output maps and sorted target tables.

The primary goals of the airborne MTADS Dem/Val program are enumerated below:

1. Field an airborne magnetometer array for efficiently surveying very large or inaccessible areas,

2. The system should have the capability to characterize the presence of UXO associated with impact bull's eyes or buried ordnance caches,

3. The airborne survey system will incorporate many of the successful developments associated with the vehicular MTADS, including sensors, satellite-based navigation, efficient data acquisition approaches, and the DAS suite of utilities for data manipulation and target analysis,

4. The system should create a permanent record in global coordinates of the positions of all targets, and

5. The intended use of this airborne automated technology is for site characterization of DoD bombing and target ranges. The system must be capable of efficiently and rapidly surveying relatively large areas typical of ranges used during and since WW II that occupy millions of acres.

1.2 Objective of the Demonstration

This Demonstration had three primary objectives. First, we demonstrated the airborne MTADS in a new geological environment against a new target set. Second, the probability of detection and location accuracy of the airborne system was measured against the baseline vehicular system. The targets for this comparison included the existing practice bombs as well as an emplaced target suite chosen by ESTCP. And, finally, the MTADS airborne system was

measured against the system developed and deployed by Oak Ridge National Lab. This intersystem comparison will allow the Institute for Defense Analyses to quantify the performance features of each system.

1.3 Official DOD Requirement Statement

The Navy Tri-Service Environmental Quality Research Development Test and Evaluation Strategic Plan specifically addresses under Thrust Requirements l.A.1 and 1.A.2, the requirements for improved detection, location and removal of UXO on land and under water. The index numbers associated with these requirements are 1.I.4.e and 1.III.2.f. The priority 1 rankings of these requirements indicate that they address existing statutory requirements, executive orders or significant health and safety issues. Specifically the requirements document states:

> *There are more than twenty million acres of bombing and target ranges under DOD control. Of particular concern for the Navy are the many underwater sites which have yet to be characterized. Each year a significant fraction (200,000-500,000 acres) of these spaces are returned to civilian (Private or Commercial) use. All these areas must be surveyed for buried ordnance and other hazardous materials, rendered certified and safe for the intended end use. This is an extremely labor intensive and expensive process, with costs often far exceeding the value of the land.... Improved technologies for locating, identifying and marking ordnance items must be developed to address all types of terrain, such as open fields, wooded areas, rugged inaccessible areas, and underwater sites*.[13]

The MTADS vehicular system addresses all aspects of the Tri-Service Requirements for land-based buried UXO. It is designed to survey large sites rapidly and efficiently, with commensurate economic benefits. Moreover, it is capable of detecting all classes of buried UXO at their likely self-burial depths. The detection capability of the airborne system is reduced for smaller targets as will be demonstrated below. Both systems will correctly locate buried targets, determine their burial depths, classify the likely ordnance size, provide for future target way pointing, as well as create GIS-compatible target output maps and sorted target tables.

2. Technology Description

2.1 Technology Development and Application

2.1.1 Vehicular Magnetometer System

The MTADS hardware consists of a low-magnetic-signature vehicle that is used to tow linear arrays of magnetometer and pulsed-induction sensors to conduct surveys of large areas to detect buried UXO.[14] The MTADS tow vehicle, manufactured by Chenowth Racing Vehicles, is a custom-built off-road vehicle, specifically modified to have an extremely low magnetic

signature. Most ferrous components have been removed from the body, drive train and engine and replaced with non-ferrous alloys.

The MTADS magnetometers are Cesium-vapor full-field magnetometers (Geometrics Model 822ROV) selected for low noise and inter-sensor reproducibility. An array of eight sensors is deployed as a magnetometer array on an aluminum and composite platform, Figure 1. The sensors are sampled at 50 Hz and typical surveys conducted at 6 mph; this results in a sampling density of ~6 cm along track with a sensor spacing of 25 cm. The time-variation of the Earth's field is measured by a ninth sensor deployed at a static site removed from the survey area. These data are used to correct the survey magnetic readings.

Fig. 1– Vehicular MTADS magnetometer system deployed at Isleta Pueblo, Albuquerque, NM

The sensor positions are measured in real-time (5 Hz) using Real Time Kinematic (RTK) Global Positioning System (GPS) technology which results in position accuracies of ~5 cm. All navigation and sensor data are time-stamped with Universal Coordinated Time (UTC) derived from the satellite clocks and recorded by the data acquisition computer (DAQ) in the tow vehicle. The sensor, position, and timing files are downloaded periodically throughout a survey onto magnetic disks and transferred to the Data Analysis System (DAS) for analysis.

2.1.2 Airborne Magnetometer System

The airborne MTADS system hardware includes an array of seven total field magnetometers mounted on a Bell Helicopter Model 206L series "Longranger." The MTADS magnetic sensors are Cs vapor full-field magnetometers (a variant of the Geometrics 822 sensor, designated as the Model 822A). The helicopter with the magnetometer array mounted is shown in Figure 2. All sensors are interfaced to a data acquisition computer (DAQ). The DAQ electronics are contained in a rack mounted in the rear starboard seat position in the helicopter, Figure 3. The interface to the helicopter power and power distribution system is also in the rack, as are readouts for all the sensor inputs. The survey progress is monitored continually by an operator in the rear port seat.

Fig. 2 – MTADS Airborne magnetometer system deployed at Isleta Pueblo, NM

In the 9-meter boom, the seven sensors are mounted with a 1.5 meter horizontal spacing. The specially-selected magnetometers, which are airborne quality, were acceptance tested at the manufacturer's facility to verify sensitivity, sensor noise, heading error, dead zones, inter-sensor compatibility, and performance with the multi-sensor interface modules.

The sensor positions above the surface of the Earth (latitude, longitude, and height above ellipsoid) are determined using satellite-based GPS navigation, employing the latest Real Time Kinematic (RTK) technology, which provides a real-time position update (at 20 Hz) with an accuracy of about 5 cm. GPS satellite clock time is used to time-stamp both position and sensor data information for later correlation.

Fig. 3 – MTADS airborne DAQ mounted in the rear seat of the survey helicopter

The helicopter pilot flies the survey using an onboard navigation guidance display, Figure 4. The survey parameters are set up in a second computer that supports the pilot display. This computer shares the GPS navigation data with the DAQ. The survey guidance display provides left-right of track indicator, altitude indicator, an automatic line number increment, an adjustment for lateral offset, a color-coded flight swath overlay, and the ability to zoom in or out on the display. The survey course-over-ground (COG) is plotted for the pilot in real time on the display, as are presentations showing the data quality for the altimeter and GPS and the GPS navigation fix quality. This allows the operator to respond to both visual cues on the ground and to the survey guidance display. Following a survey, the operator can survey any missed areas before leaving the site.

Fig. 4 – Two views of the pilot guidance system

2.1.3 Data Analysis Methodology

For the vast majority of MTADS surveys, the MTADS Data Analysis System has been used to convert the sensor and position data files into an anomaly map by interpolating the individual sensor readings using the GPS-derived positions. The DAS software was developed specifically for the MTADS program as a stand-alone suite of programs. PC-based code is now available and has been used for recent operation. The DAS is written for use by both sophisticated and novice users. Even the novice can perform a complete anomaly analysis using menu-driven tools and default settings. For the advanced user, there is an extensive range of options available including navigation data cleanup, sensor nulling and leveling, noise filtering, etc. A working screen of the DAS is shown in Figure 5.

In the case of isolated ordnance targets in the far field (i.e. farther from the sensors than their characteristic dimension) the DAS employs resident physics-based models to determine target

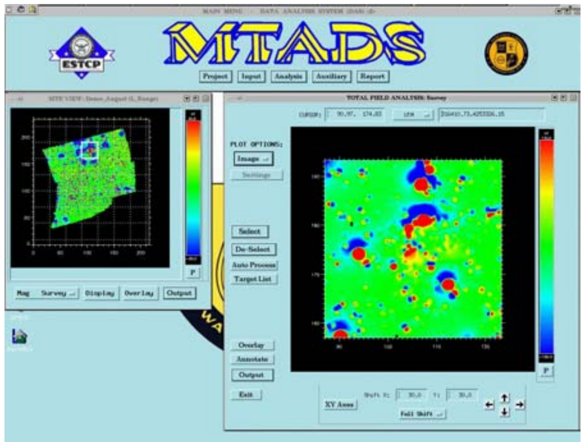

Fig. 5 – Working screen of the MTADS DAS showing the project view on the left and an expanded analysis view on the right

size, position, and depth. Extensive data sets have been acquired and processed to calibrate these models. Using these models, we have demonstrated probabilities of detection of 95 to 97% and location accuracies of 15 cm with the vehicular magnetometer system.

Although we have achieved impressive results using the DAS, it has proven difficult to transition to the general UXO user community. Beginning with the demonstrations of the airborne system, we have performed the data preprocessing functions through generation of mapped data files using a commercial software package, Geosoft Oasis montaj™. An example of a working screen from montaj™ is shown in Figure 6. The upper panel of the screen shows a portion of the Oasis database, the middle shows corrected and uncorrected plots of one of the sensor tracks and the lower panel shows a detail of the interpolated sensor data.

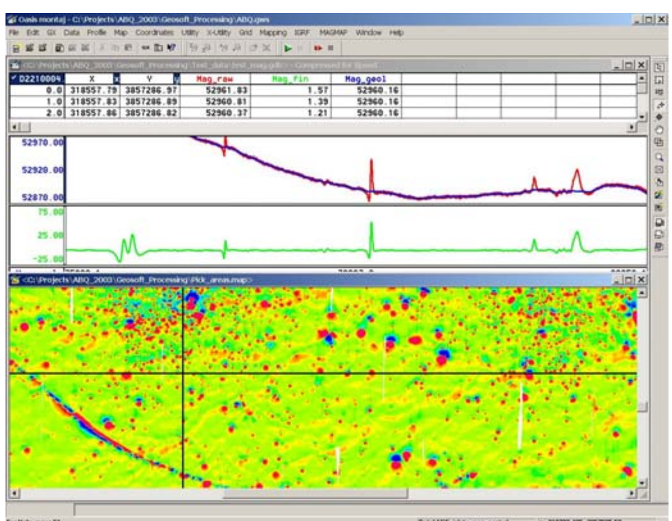

Fig. 6 – A working screen of Oasis montaj™ showing airborne data from this Demonstration

At this point in our development, we import the mapped data files generated using montaj™ into the DAS for target selection and analysis. We are in the process of converting the analysis routines developed under ESTCP and SERDP sponsorship to Geosoft GXs, executable files that can be called from the Oasis environment. This will allow us to perform the entire data analysis from input of raw data files through data quality checks, mapping of individual sensor readings, target selection, model fit, and finally generation of target lists and output graphics in the Oasis environment. All target analyses reported here were accomplished using routines in the MTADS DAS.

2.2 Previous Testing of the Technology

As mentioned above, the vehicular MTADS, which will serve as the comparison benchmark for this Demonstration, has been tested at a wide variety of sites over the past six years.[2-12] Of particular relevance is the demonstrated ability of the vehicular system to locate ordnance of the type to be encountered here with a mean location error of 12 cm and a 95% location distance of 29 cm.[5] Thus, the vehicular MTADS magnetometer system is ideal as a performance benchmark.

The airborne *MTADS* adjunct has been demonstrated three times at two sites over the past year and a half. The first full-scale demonstration was at the Badlands Bombing Range on the Pine Ridge Reservation in South Dakota in September 2001. During this demonstration a 10-acre site seeded with 25 inert projectiles (105-mm, 155-mm, and 8-inch) was flown to allow comparison of the system performance with that of the vehicular MTADS, which surveyed the same site. An additional 1600 acres were surveyed using the airborne system as part of continued clean-up efforts over the entire Impact Area. Analysis of the airborne data collected over the seeded site resulted in a total of 161 targets selected for digging including all of the seeded projectiles and one live, HE filled, 155-mm projectile.[15] The false alarm ratio for this site was 161/26 = 6.2. A total of 1,193 targets were analyzed from the 1600 acre survey, resulting in 528 excavations and recovery of a total of 19 live UXO projectiles including eleven 155-mm and eight 8-inch projectiles.[15]

The second Demonstration of the airborne system was at Aberdeen Proving Ground in late July 2002. This demonstration involved an airborne survey of a total of 550 acres over selected sites, including a 94-acre calibration area and 770 additional acres over areas with varying terrain types, and UXO/clutter contamination levels. At this time, results are only available from the Phillips Air Field area, which was a seeded area containing 105-mm projectiles and 60- and 81-mm mortars. Even though the mortars are near, or below, the reliable detection threshold for the airborne system depending on geologic and system noise levels, the airborne MTADS achieved an overall P_d of 0.85 which comprised 1.0 for the 105-mm projectiles, and 0.67 for each of the mortar sizes. This level of detection was achieved because the site conditions allowed for extremely low survey altitudes (sensors at 1m or less). Further reporting awaits the results of a series of excavations in progress on targets reported by the NRL and Oak Ridge systems.

The most recent Demonstration of the airborne MTADS was again at the Badlands Bombing Range in September 2002. This demonstration was a combined vehicular, man-portable, and airborne survey of the remaining area of the Impact Area not covered in the 2001 survey. The survey data collected in this demonstration have been analyzed and reported.[16] Remediation funding is not available at this time for the targets analyzed in the Demonstration.

2.3 Factors Influencing Cost and Performance

The largest single factor affecting the airborne MTADS survey costs and production rates is the cost of operating the survey helicopter on site. During recent surveys, we have paid approximately $700 per hour with a four hour daily minimum. Mobilization of the aircraft to and from the site from its home base is charged at these same rates. Therefore, to maximize production at minimum cost, surveys must be arranged with long survey lines to minimize the time spent in turns, frequent examinations of data quality to minimize time spent taking unacceptable data, minimal time lost to aircraft refueling by having fuel available on site, and aircraft basing to minimize daily ferry to and from the survey site.

2.4 Advantages and Limitations of the Technology

Unlike the vehicular magnetometer system, the airborne system is not capable of detecting the smallest classes of buried UXO at depth. However, we have taken data from Target N9 on the Laguna Pueblo, which has over 15,000 M38 practice bombs, resampled the data and modeled the magnetic response that would be observed by an airborne sensor array above the ground. While the magnetic signals are spatially spread and diminished in intensity as the sensors move further above the ground, our results indicate that, at an altitude of 2 meters above the ground, the system should be capable of detecting BDU-33s or Mk 82s in all but the most active geological environments and ordnance targets equivalent to or larger than 2.75-in warheads in geologically quiet areas.

In practice, the absolute limit of detection is limited by the background noise level, which is a combination of the geophysical noise and the platform-induced noise from the helicopter. The treatment of magnetometry data to correct for airborne platform-induced signals uses a standard technique called aeromagnetic compensation. This technique uses commercially-available equipment and reduces the platform-induced magnetic noise for fixed wing aircraft to on the order of 0.01 nT. This approach has been widely used in the geophysical exploration community on both fixed wing aircraft and for helicopters. Depending on the techniques used, and the type of platform, the compensation can reduce the platform and heading noise to 0.1-0.5 nT. This is well below the typical geophysical noise due to magnetic soils and rocks. The signal intensity from an individual ordnance item the size of a GP bomb (or an individual cache of ordnance) is a few tens to several hundred nT, even at several meters altitude. The ability to detect and characterize an isolated large target is therefore not a matter of signal strength or signal-to-noise ratio, but a matter of having a data sampling density high enough to identify the target as a target and to characterize its magnetic anomaly signature using dipole-fitting routines. These issues were incorporated into the design of the horizontal array spacing and the flying speed.

On large open ranges the vehicular MTADS provides an efficient survey technology. Surveys with the magnetometer array often exceed production rates of 20 acres per day. When a site has vegetation cover or topography that precludes vehicular traffic, the man-portable adjunct MTADS can often be used. However, there are sites that cannot be traversed on foot, others that are dangerous, and still others that contain isolated bombing targets or impact ranges, located at best imprecisely, within tens or hundreds of thousands of acres. For these sites, the Airborne MTADS will produce much more rapid and efficient surveying, with the commensurate economic benefits. The Airborne MTADS is capable of survey production rates of 50 acres/hour.

The helicopter is typically flown at a low altitude (1.5 - 5 meters), with an array horizontal sensor spacing of 1.5 meters, and the forward velocity of 10 - 20 meters per second. To achieve this, the sensors have been fixed to hard points on the helicopter. As seen in Figure 2, the sensor boom extends well in front of and is clearly visible to the pilot; this is important for low altitude flights. With the sensor spacing of 1.5 meters, a data collection rate of 100 Hz, and a speed over ground of 20 m/sec, the data density provides 50 data points on a typical target to fit the dipole signature. Any yaw in the helicopter attitude during surveying decreases the effective sensor spacing, requiring adjacent survey lines to be flown closer together.

3. Demonstration Design

3.1 Performance Objectives

This Demonstration consisted of three overlapping surveys. First, a vehicular magnetometery survey of 100 acres near the previously-identified bull's eye, S1, on the Isleta Pueblo near Albuquerque, NM was planned. Targets on this area were expected to be M38 and BDU-33 practice bombs and an array of ordnance to be emplaced by the Army Engineering R&D Center at the direction of the ESTCP Program Office. Second, an airborne magnetometry survey of 1500 acres around the target to include the vehicular area. Finally, an airborne survey by Oak Ridge National Lab of the same 1500 acres.

The vehicular results will be used as a comparison benchmark for the results of the two airborne systems. Consequently, all the targets within the vehicular survey were to be analyzed and fit. In practice, only ~64 acres were completely surveyed by the vehicular system as will be discussed below. Target analysis of these survey data identified 1364 targets that were analyzed and reported to ESTCP and IDA. Each of the airborne survey teams independently analyzed their data using the same target-ranking scheme (i.e. likelihood of UXO vs. non-UXO on a scale of 1 to 6) as the vehicular system. All three analyses were submitted to ESTCP and IDA at the conclusion of the surveys as an Excel (*.xls) file.

From these analyses, an inclusive dig list was prepared by IDA as an Excel file and submitted to NRL for transmission to the dig teams. Each target was to be excavated, precisely located using GPS, documented, and photographed. OE scrap was collected for later certification and disposal. Recovered live ordnance was handled at the discretion of the UXO supervisor on site, primarily by blowing in place. All excavations were filled, tamped, and returned to grade.

The specific objective of this Demonstration was to produce a quantitative comparison among the airborne systems, including probability of detection and false alarm rate. These quantities will be calculated as a function of threshold parameter where possible so that an ROC-type analysis can be performed.

3.2 Selecting the Test Site

The location for this Demonstration was chosen by the ESTCP Project Office in conjunction with the Environment Department of the Pueblo of Isleta. Subsequent to the choice of sites, representatives of the NRL and Oak Ridge teams met at the site with Mr. Jim Piatt, the Director of the Environment Department, walked several of the possible targets, and settled on Target S1 for this survey. This target was chosen because it is of most concern to the tribe, it has the greatest possibility of containing HE-filled UXO since the tribe has located some heavy-wall fragments on the site, and it offers the opportunity to survey the largest area within the available resources.

3.3 Test Site History/Characteristics

"The Pueblo of Isleta is located in north-central New Mexico, approximately 10 miles south of Albuquerque. The Reservation is bordered on the north by the Sandia Military Reservation, which includes Kirtland Air Force Base, the Manzano Mountains on the east, and the Rio Puerco and Laguna Pueblo Reservation on the west."[17] The area referred to as Site B in the Draft Site Assessment Report,[17] which contains target S1, comprises an area of approximately 7000 acres that were leased from the Tribe in the 1950's for use as a target bombing range for aircraft from Kirtland. Documentation in Bureau of Indian Affairs files indicate that this area was used as a practice bombing range from 1956 to 1961 to determine the performance of fast aircraft during bombing runs. In the 1960's, Kirtland collected and piled visible ordnance debris for removal. Up to 2 tons of practice bombs and ordnance waste per acre were removed but no explosive ordnance was found.

3.3.1 Climate and Weather

During the month of February, the normal high temperature in Albuquerque is 53 °F with a normal low of 26 F. The average temperature is 41 °F. Of more importance for survey work, February is the second driest month historically with normal precipitation of just under 0.5 inches. In February 2002, the mean wind was less than 2 mph from the SW.

The conditions during 2003 were less benign. Los Lunas, the reporting station nearest the site, received nearly three times the historical mean rain during February 2003. This complicated delivery of our survey equipment and supplies to the site. After one particularly hard rain, road conditions prevented MTADS personnel from reaching the site. During the entire month, the area had a more active weather pattern than usual resulting in several periods in which the winds were too high for low-level airborne surveys as will be detailed in the survey log below.

3.3.2 Topography

The site consists of open, semi-arid terrain. The area is relatively flat, open grassland with elevation increasing from 5100 feet above sea level on the west to a maximum of 5400 feet above sea level and a broken escarpment on the east.

3.3.3 Site Maps and Photographs

Figure 7 is a portion of a USGS 7.5-minute topo map showing the location of Target S1 with the approximate boundaries of the proposed surveys outlined. The most direct access to the site is by a dirt road that exits to the north from New Mexico Highway 6, 14 miles west of Exit 203 off Interstate 25. This dirt road is maintained by Isleta Pueblo personnel. An NRL contractor, Geometrics GPS, Inc. of Fredericksburg, VA, has established two geodetic survey points near Target S1 and four more on various other targets on the Pueblo's Comanche Ranch. The approximate positions of the two first-order points near S1 are indicated in Figure 7. The coordinates of all six points are given in Table 1. An example of the predominant M38s and one of the few heavy-walled fragments is shown in Figure 8.

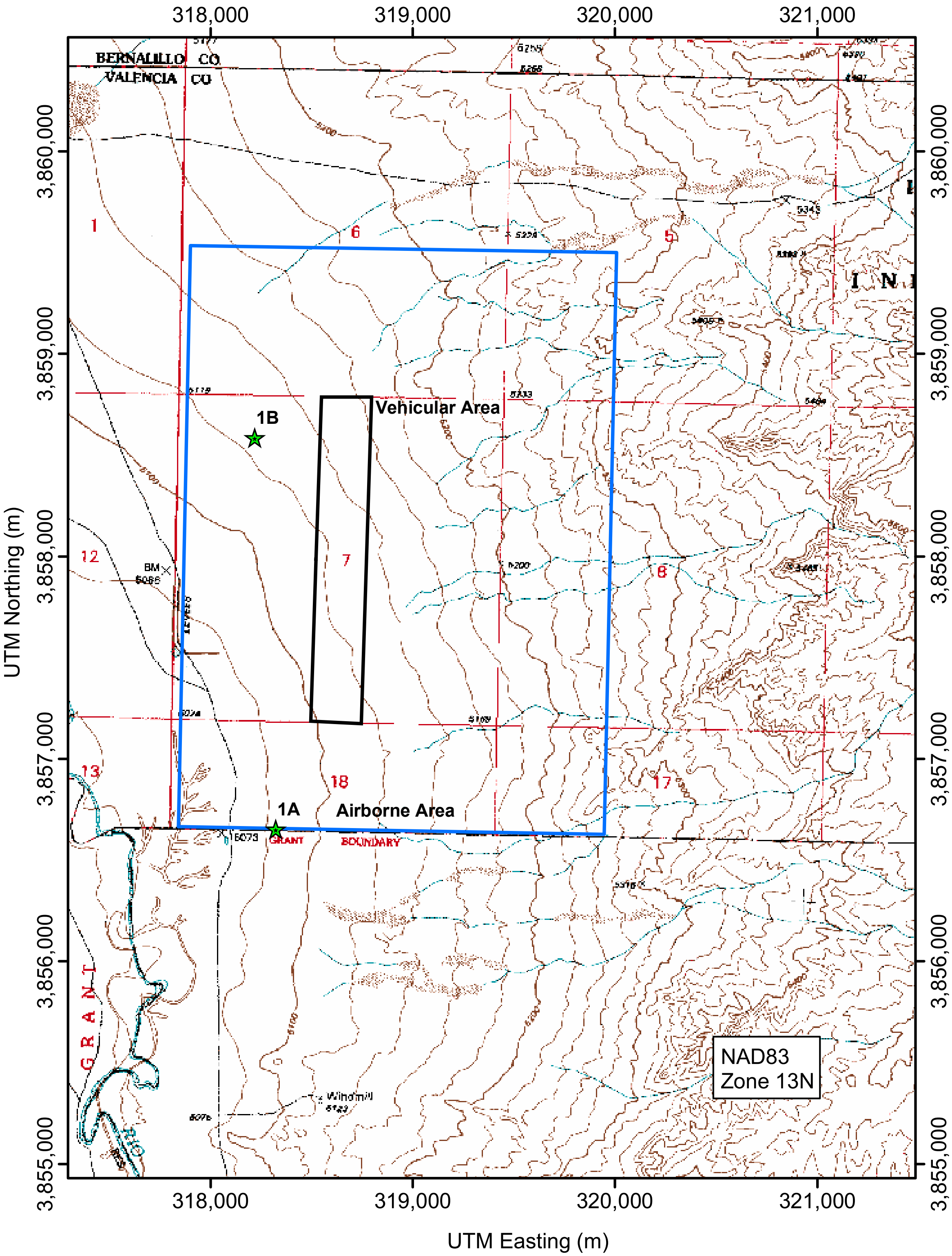

Fig. 7 – A portion of a USGS topo map showing the boundaries of the planned survey areas. The locations of the two first-order points installed for this survey are shown as stars.

Table 1. Isleta Survey Coordinates Installed for this Demonstration

Point	Latitude	Longitude	Northing (m)	Easting (m)	Ellipsoid Height (m)
			NAD 83		
1A	34° 50' 09.53499" N	106° 59' 12.69597" W	3,856,654.157	318,321.948	1528.443
1B	34° 51' 12.19331" N	106° 59' 18.29422" W	3,858,587.492	318,218.027	1541.863
2	34° 41' 21.33042" N	106° 54' 36.41382" W	3,840,244.133	325,030.974	1486.639
3	34° 33' 12.69605" N	106° 56' 50.72926" W	3,825,255.338	321,322.056	1535.667
7	34° 31' 20.82374" N	107° 03' 41.28845" W	3,822,016.365	310,786.481	1616.955
8	34° 40' 03.72964" N	107° 05' 21.49078" W	3,838,179.459	308,565.015	1702.621

Fig. 8 – Photograph of the M38 practice bombs (left panel) and one of the few heavy-walled fragments (right panel) found on the site

3.4 Testing and Evaluation Plan

3.4.1 Pre-Demonstration Activities

The MTADS vehicular system as well as components of the airborne system were mobilized to the Isleta Pueblo S-1 site in a rented 53-ft trailer. The tow vehicle, the magnetometer trailer, notebook computers for the DAS and Oasis montaj™, an office PC, GPS equipment, batteries and chargers, office equipment, radios and chargers, tools, equipment spares, and maintenance items, and the airborne boom components and magnetometers were transported in the trailer. A government contract transportation firm transported the trailer to the site. The helicopter was mobilized to the site by the helicopter charter firm, Helicopter Transport Services.

Due to the remoteness of the survey site, no essential support services were available on-site. Accordingly, NRL made provisions to acquire all of the requisite supplies, materials, and facilities from rental firms in Albuquerque. For this operation one trailer was used exclusively

for data processing and analysis, as a communications center, battery storage and charging stations, an electronics repair station, and storage for spares and supplies. This trailer had AC power and heat. A second 8 foot x 48 foot trailer, which could be fully opened from either end (for drive through), was used to garage and for secure storage of the MTADS vehicle and sensor platform. Power to the trailers was provided by a 65 KW diesel field generator that was also used to recharge the vehicle, radios and GPS batteries overnight. Communications among on-site personnel was provided by hand-held VHF radios, with a base station located in the command trailer. Radios were provided to all field and office teams. Cellular phone service was sporadically available at the office trailer with more reliable service in the hills to the east or on the state highway. Fuel storage was provided for the AC generator and two portable toilets were provided to support all field and office crews with weekly servicing. Figure 9 shows the arrangement of the MTADS base camp for this survey. Aviation fuel to support the airborne survey was also located on-site although at some distance from the trailer area. The combination of an on-site fuel supply and our ability to base the helicopter at a nearby community airport (Belen, NM) allowed us to complete the survey with only 4.1 hrs non-survey helicopter time.

Fig. 9 – Photograph of the MTADS base camp for this survey showing the office and garage trailers, generator, diesel tank, and transport trailer. The aviation fuel depot is not shown in this photo.

The area around Target S1 was divided into two survey sites in the planning stages of this Demonstration. A larger, 1500-acre, site was designated for the two airborne systems. Within this site, a second, 100-acre site contained the seed ordnance and was to be surveyed by the vehicular system. The coordinates for the both areas are given in Table 2.

Table 2. Coordinates for the Corners of the Two Surveys

Point	**Latitude**	**Longitude**	**Northing (m)**	**Easting (m)**
			NAD 83	
Air-NW	34° 51' 42.726"N	106° 59' 31.494"W	3,859,534.87	317,901.48
Air-NE	34° 51' 42.972"N	106° 58' 08.556"W	3,859,500.82	320,007.88
Air-SE	34° 50' 09.696"N	106° 58' 08.724"W	3,856,627.06	319,947.15
Air-SW	34° 50' 09.576"N	106° 59' 31.632"W	3,856,664.97	317,840.93

Point	Latitude	Longitude	Northing (m)	Easting (m)
			NAD 83	
Vehicle-NW	34° 51' 18.912"N	106° 59' 05.400"W	3,858,788.00	318,549.62
Vehicle -NE	34° 51' 19.038"N	106° 58' 55.650"W	3,858,786.99	318,797.32
Vehicle -SE	34° 50' 26.694"N	106° 58' 56.400"W	3,857,174.63	318,746.38
Vehicle -SW	34° 50' 26.940"N	106° 59' 06.294"W	3,857,187.19	318,495.20

3.4.2 Period of Operation

The NRL portion of the demonstration survey was accomplished from Wednesday, February 19th through Thursday, February 27th. The start of the survey was delayed two days from the planned start due to the mid- February snow on the East Coast that closed all area airports for several days. The vehicular survey was terminated one day earlier than planned because of a terminal equipment failure. The details of the airborne survey are given in Table 3 and the vehicular survey in Table 4.

For bookkeeping convenience, the original airborne survey area was divided into 12 sorties of 25 survey lines each (175m east to west). These planned sorties and their relation to the vehicular site are shown schematically in Figure 10. An additional sortie was added to the west side of the survey when the eastern edge proved too hilly and tree-covered for efficient surveying.

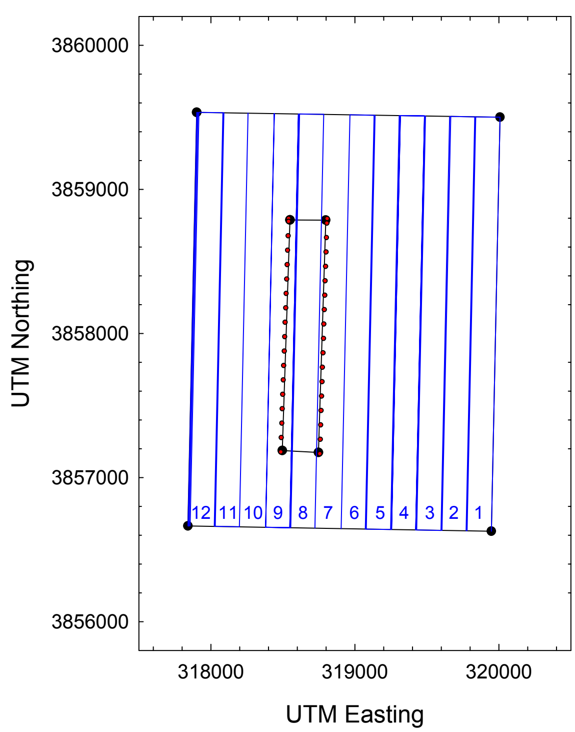

Fig. 10 – Layout of the 12 planned airborne sorties (blue lines) showing their relation to the vehicular area (black lines)

Table 3. Details of the Airborne Survey

Date	Activity	Survey Base Name	Duration (min.)
Wed., Feb 19th	MTADS personnel arrive at site. Unpack trailer and set up office. Transport airborne components to Belen, NM airport and assemble sensor boom.		
Thurs, Feb 20th	Aircraft arrives ABQ late afternoon. Assemble boom supports to aircraft.		
Fri, Feb 21st	Ferry aircraft to Belen. Installation complete by 10:30. High winds prevent survey. Test flight conducted late in the day.	03053004	14
Sat, Feb 22nd	Replace Mag Sensor #6		
	Survey Tracks 1-15 of sortie 7	03054001 30354002	49 34
	Survey Vehicular Site (Tracks 23-25 of sortie 7 and all of sortie 8)	30354003 30354004 03054005	56 59 51
Sun, Feb 23rd	Sortie 9	03355003 03355004 03055005	61 20 60
	Tracks 15 – 23 of sortie 7	03055006	51
	Test flight for eastern edge of site. Track 1 of both sorties 1 and 2	03055007	14
	Sortie 3	03055008 03055009 03055010	44 42 44
	Tracks 1-17 of sortie 4	03055011 03055012	24 57
Mon, Feb 24th	Tracks 15 – 25 of sortie 4	03056001	47
	Sortie 5	03056002 03056003 03056004	45 43 29
	Sortie 6	03056005 03056006 03056007	61 19 37
	Tracks 1 – 10 of sortie 10	03056008	47

Date	Activity	Survey Base Name	Duration (min.)
Tue, Feb 25th	Tracks 8 – 25 of sortie 10	03057001 03057002	60 17
	Sortie 11	03057003 03057004 03057005	39 45 28
	Sortie 12	03057006 03057007 03057008	43 50 23
	Sortie 13	03057009 03057010 03057011 03057012	45 9 45 34
	Re-survey tracks 11 and 12 of sortie 3	03057013	15
	Remove equipment from aircraft Aircraft departs site for ABQ and ferry home		
Total survey time minus test flight		**24 hrs 7 min**	

Table 4. Details of the Vehicular Survey

Date	Activity	Survey Base Name	Duration (min.)
Mon, Feb 24th	Static Test	03055001	26
	Site Survey	03055002	55
Tue, Feb 25th	Site Survey	03056001 03056002 03056003 03056004 03056005	31 28 58 60 58
	Calibration Area	03056006 03056007	61 17
	Site Survey	03056008 03056009	55 58
Wed, Feb 26th	Site Survey	03057001 03057002 03057003	58 19 59

Date	Activity	Survey Base Name	Duration (min.)
Wed, Feb 26th (continued)		03057004	50
		03057005	29
		03057007	58
		03057008	15
		03057009	57
		03057010	31
	Calibration Area infill	03057011	2
	03056004 infill	03057012	4
Thurs, Feb 27th	Site Survey	03058001	60
		03058003	61
		03058004	61
		03058005	63
		03058006	58
		03058007	52
		03058008	30
	Sensor boom delaminates, survey terminated		
Fri, Feb 28th	Pack equipment for shipment. MTADS personnel depart site.		
Total survey time minus static test		**20 hrs 48 min**	

3.4.3 Area Characterized

The vehicular MTADS system covered 28.1 hectares (69.5 acres) including a 10-m buffer around the vehicular site, Figure 11. In this area, we marked 1364 targets (16 of these were the calibration targets planted in the upper part of the site) for remediation using the now familiar classification scheme of 1 for high-confidence ordnance, 2 for medium-confidence ordnance, 3 for low-confidence ordnance, 4 for low-confidence clutter, 5 for medium-confidence clutter, and 6 for high-confidence clutter. A breakdown of the distribution of these picks is given in Table 5. An example page of the vehicular target list is in Table 6 and the entire list is included as Appendix A.

Table 5. Vehicular MTADS Target Picks Reported by Analyst's Classification

UXO Classification	Cal	1	2	3	4	5	6	Total
Number of Picks	16	305	328	322	239	137	17	1364

Table 6. A Sample of the MTADS Vehicular Target Report for the Vehicular Area

Target ID	UTM E (m)	UTM N (m)	Depth (m)	Size (m)	Moment	Incl.	Azim.	Fit Quality	Analyst's Comments	UXO Category	Latitude	Longitude
1	318557.47	3858778.94	0.37	0.053	0.078	51	75	0.943	81mm mortar - serial #206	cal	34.855173011	-106.984745505
2	318570.85	3858778.12	0.34	0.079	0.257	59	54	0.984	105mm proj - serial # 208	cal	34.855168015	-106.984599028
3	318582.15	3858774.76	0.26	0.038	0.028	62	3	0.945	60mm mortar - serial # 60	cal	34.855139755	-106.984474827
4	318592.92	3858777.26	0.35	0.128	1.074	44	84	0.989	105mm mortar - serial # 209	cal	34.855164212	-106.984357519
5	318603.49	3858777.82	0.26	0.210	4.810	3	93	0.998	2.75in rocket - serial # 810	cal	34.855171164	-106.984242144
6	318644.95	3858773.30	0.43	0.075	0.217	62	92	0.987	81mm mortar - serial # 207	cal	34.855137846	-106.983787876
7	318659.24	3858774.39	0.44	0.093	0.416	37	5	0.986	81mm mortar - serial # 208	cal	34.855150221	-106.983631930
8	318673.61	3858773.72	0.42	0.151	1.766	30	14	0.993	105mm proj - serial # 211	cal	34.855146722	-106.983474620
9	318687.04	3858775.51	0.22	0.061	0.119	35	303	0.947	60mm mortar - serial # 64	cal	34.855165222	-106.983328224
10	318699.22	3858772.76	0.38	0.245	7.559	23	92	0.975	2.75in rocket - serial # 803	cal	34.855142648	-106.983194440
11	318720.48	3858772.06	0.34	0.123	0.968	15	9	0.994	105mm proj - serial # 213	cal	34.855140113	-106.982961845
12	318736.84	3858771.62	0.37	0.071	0.182	30	21	0.972	81mm mortar - serial # 209	cal	34.855139024	-106.982782882
13	318756.48	3858773.67	0.22	0.078	0.249	4	187	0.984	60mm mortar - serial # 65	cal	34.855161006	-106.982568588
14	318774.03	3858772.50	0.35	0.232	6.482	-25	184	0.989	2.75in rocket - serial # 805	cal	34.855153671	-106.982376513
15	318797.59	3858771.99	0.30	0.261	9.161	10	7	0.968	2.75in rocket - serial # 800	cal	34.855153209	-106.982118782
16	318623.26	3858773.64	0.22	0.051	0.070	20	22	0.976	60mm mortar - serial # 77	cal	34.855137015	-106.984025094
17	318510.16	3857181.40	0.63	0.193	3.688	38	23	0.995	M38	1	34.840767196	-106.984916880
18	318532.18	3857177.87	1.77	0.201	4.172	86	153	0.922	M38 outside boundary	1	34.840739298	-106.984675387
19	318557.25	3857173.06	0.49	0.044	0.045	18	38	0.891	possible 60mm outside boundary	3	34.840700457	-106.984400351
20	318573.86	3857183.62	0.30	0.043	0.042	9	35	0.896	possible 60mm	3	34.840798531	-106.984220994
21	318586.79	3857181.62	0.13	0.058	0.103	9	271	0.971	remanent	4	34.840782789	-106.984079308
22	318585.28	3857175.08	0.46	0.090	0.378	23	13	0.986	M38 oustide boundary	2	34.840723614	-106.984094367
23	318583.09	3857173.24	0.00	0.040	0.032	32	355	0.985	possible 60mm outside boundary	1	34.840706666	-106.984117938
24	318580.24	3857173.69	0.28	0.040	0.032	16	132	0.883	clutter	4	34.840710206	-106.984149201
25	318581.22	3857175.07	0.05	0.027	0.010	-14	47	0.913	small clutter	4	34.840722807	-106.984138692
26	318607.15	3857182.09	0.93	0.257	8.735	-63	28	0.779	large clutter	6	34.840790716	-106.983856803
27	318630.12	3857184.76	0.06	0.032	0.016	-42	4	0.949	small clutter	4	34.840818818	-106.983606348
28	318646.91	3857179.96	0.15	0.030	0.014	33	323	0.926	small clutter	4	34.840778574	-106.983421710
29	318658.25	3857171.76	0.50	0.338	20.012	26	4	0.966	GP bomb outside area	2	34.840706712	-106.983296033
30	318654.82	3857177.09	0.29	0.058	0.099	57	118	0.942	possible 60mm outside boundary	2	34.840754176	-106.983334649

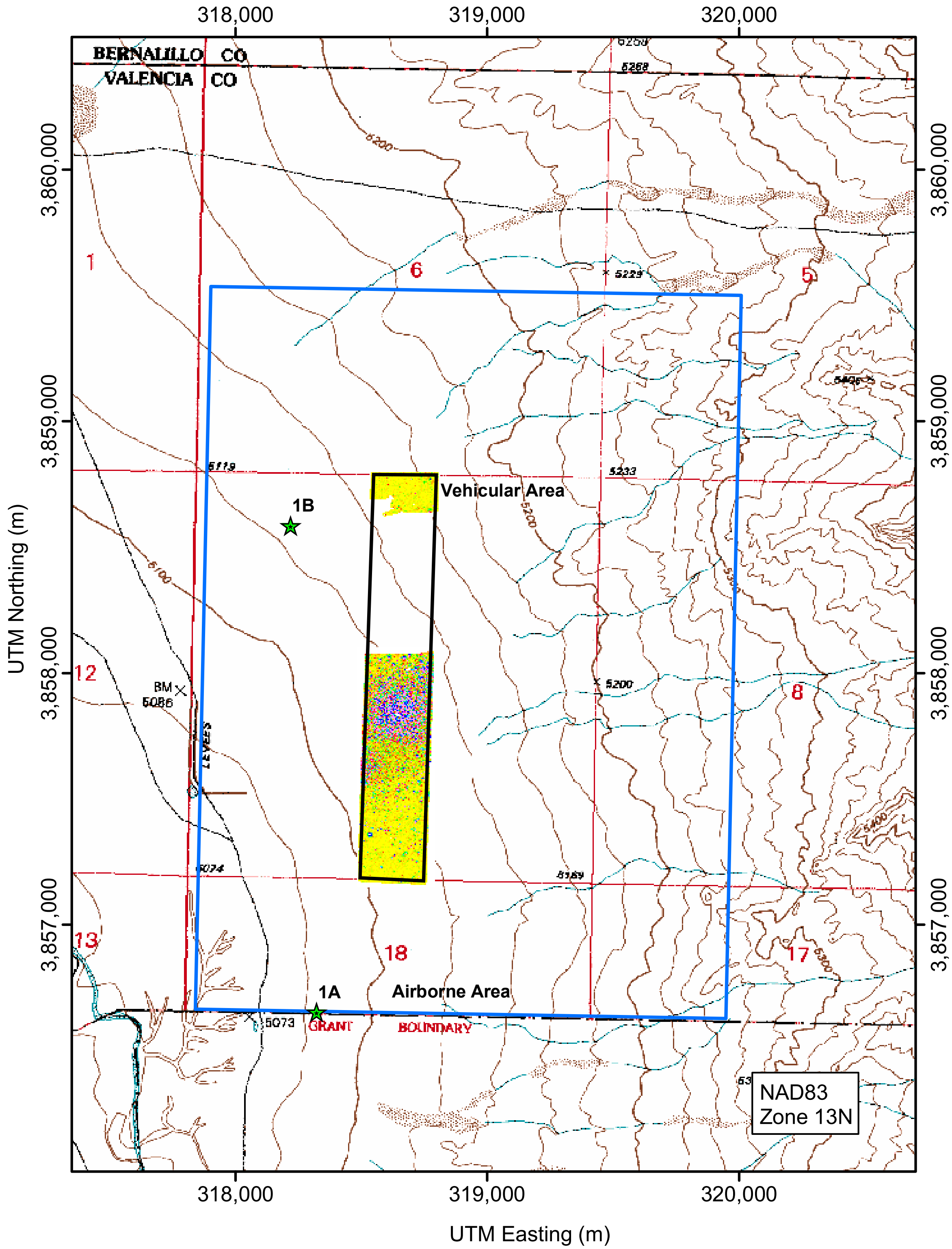

Fig. 11 – Overview of target S1 showing the portion of the site covered by the vehicular system

The airborne MTADS system surveyed 570 hectares (1408 acres), Figure 12. As mentioned above, the terrain and tree cover on the two eastern-most sorties would have required a survey at greater than three meters above the ground. This would greatly compromise our ability to detect the M38 and BDU-33 ordnance that was the target of this survey. As we were flying our survey, the Oak Ridge group was finishing up by flying this eastern area above the trees. In order to maximize the survey data that would be useful for the Pueblo, we removed sorties 1 and 2 (see Figure 10) from the flight list and added a new sortie 13 on the western edge of the site. This allowed us to cover almost to the western edge of the Pueblo's land around target S1.

Airborne targets were picked in two areas. The first area was the 100-acre vehicular site excluding the densest target area surrounding the bull's eye. These targets were picked and the target list submitted to ESTCP before the vehicular survey. Later, the ESTCP Program Office requested that the airborne analyst pick targets closer to the bull's eye. In response to this request the airborne analyst, who was not on site during the vehicular data collection and had no access to the vehicular data, expanded the portion of the 100-acre site analyzed. This resulted in 1260 targets, which are detailed in Appendix B and categorized in Table 7. An example of the target report is given in Table 8.

The second area in which targets were picked was designated the "Primary Area." This area was chosen by the ESTCP Program Office in conjunction with the two survey teams. Target analysis in this area resulted in 388 targets, which are detailed in Appendix C and categorized in Table 7.

Table 7. Airborne MTADS Target Picks Reported by Analyst's Classification

UXO Classification	**Cal**	**1**	**2**	**3**	**4**	**5**	**6**	**Total**
Vehicular Area Picks	12	502	336	282	42	69	17	1260
"Primary Area" Picks		93	85	70	48	52	40	388

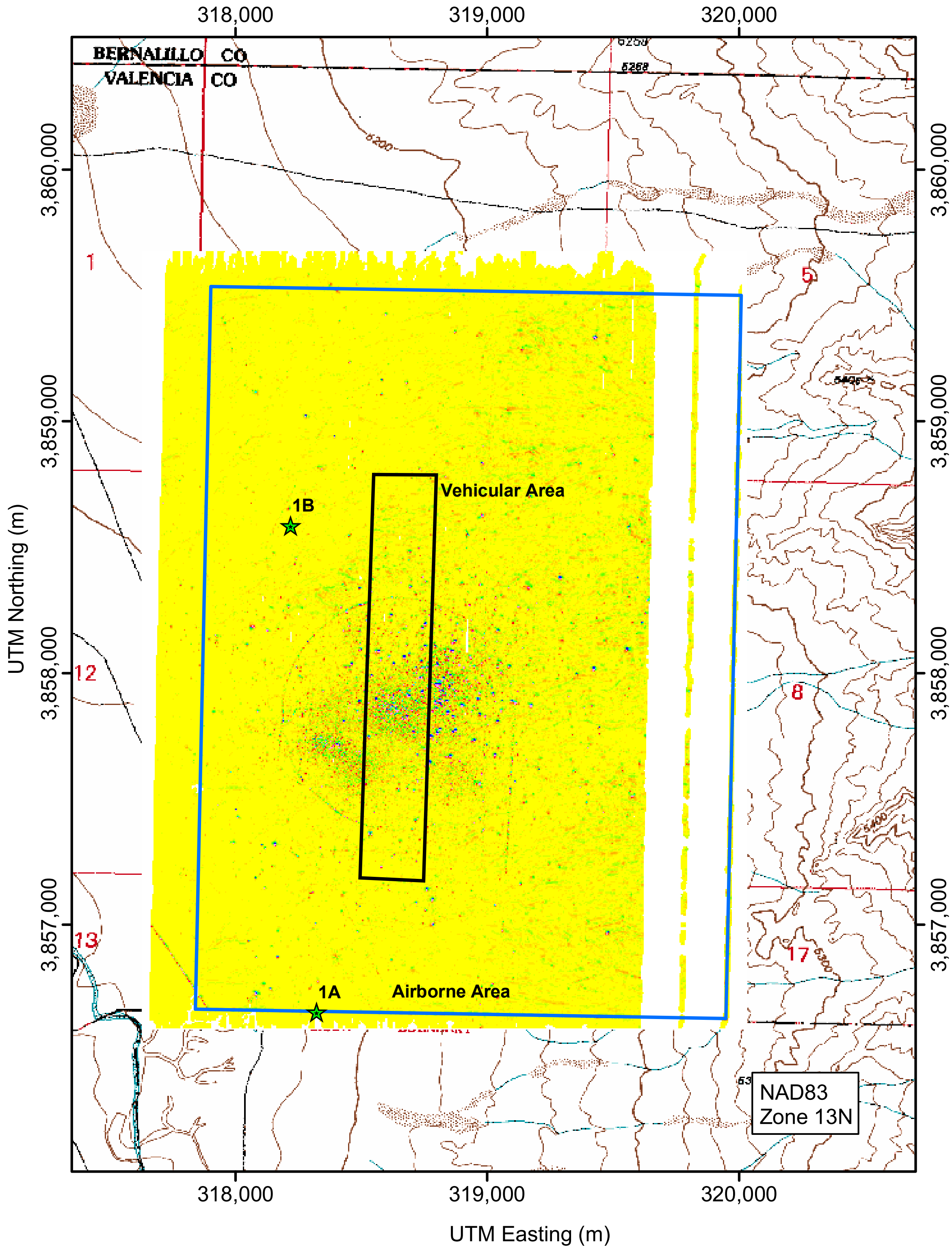

Fig. 12 – Overview of target S1 showing the portion of the site covered by the airborne system

Table 8. A Sample of the MTADS Airborne Target Report for the Vehicular Area

Targ. ID	UTM E (m)	UTM N (m)	HAE (m)	Depth (m)	Size (m)	Moment	Incl.	Azim.	Fit Quality	Analyst Comments	UXO Cat.	Latitude	Longitude
1	318594.70	3858778.90								Cal Target #4? - 105mm Mortar @ 0.25m	cal	34.85517934	-106.98433847
2	318603.44	3858777.87	1549.89	0.20	0.205	4.4610	6	94	0.988	Cal Target #5? - 2.75" Rocket @ 0.20m	cal	34.85517160	-106.98424267
3	318644.65	3858773.27	1550.49	0.17	0.056	0.0892	85	307	0.865	Cal Target #7? - 81mm Mortar @ 0.25m	cal	34.85513747	-106.98379114
4	318658.99	3858774.45	1552.06	0.00	0.038	0.0294	45	338	0.301	Cal Target #8? - 81mm Mortar @ 0.25m	cal	34.85515070	-106.98363466
5	318673.60	3858773.93	1550.94	0.32	0.133	1.2059	20	7	0.946	Cal Target #9? - 105mm Proj @ 0.25m	cal	34.85514862	-106.98347478
6	318699.86	3858772.69	1551.85	0.14	0.250	8.0344	22	98	0.975	Cal Target #11 - 2.75" Rocket @ 0.20m	cal	34.85514213	-106.98318742
7	318720.34	3858772.12	1551.42	1.07	0.176	2.8408	12	354	0.938	Cal Target #12? - 105mm Proj @ 0.25m	cal	34.85514062	-106.98296341
8	318736.36	3858771.76	1551.31	1.40	0.126	1.0376	14	350	0.897	Cal Target # 13? - 81mm Mortar @ 0.25m	cal	34.85514024	-106.98278812
9	318758.16	3858775.04								Cal Target # 14? - 60mm Mortar @ 0.15m	cal	34.85517372	-106.98255050
10	318774.03	3858772.62	1553.20	0.52	0.238	6.9617	-19	187	0.982	Cal Target #15? - 2.75" Rocket @ 0.20m	cal	34.85515469	-106.98237646
11	318797.63	3858772.00	1554.08	0.34	0.224	5.7912	6	5	0.971	Cal Target #16? - 2.75" Rocket @ 0.20m	cal	34.85515333	-106.98211834
12	318585.47	3857174.90	1534.97	0.28	0.076	0.2307	38	29	0.920	81mm 9m S of the border	2	34.84072204	-106.98409228
13	318588.04	3857181.85	1534.34	1.17	0.087	0.3419	50	277	0.737	81mm in geology	3	34.84078513	-106.98406561
14	318606.65	3857181.68	1535.62	0.22	0.201	4.1988	78	278	0.959	M38, SHALLOW	1	34.84078696	-106.98386216
15	318609.22	3857184.72	1535.42	0.70	0.078	0.2459	0	236	0.628	81MM IN CLUTTER	3	34.84081478	-106.98383480
16	318614.19	3857186.97	1535.23	0.89	0.082	0.2889	24	10	0.669	UNLIKELY DEEP 81MM	3	34.84083593	-106.98378097
17	318604.55	3857203.14	1535.49	0.49	0.106	0.6151	32	16	0.916	105MM	1	34.84097995	-106.98388979
18	318645.96	3857165.26	1535.65	1.14	0.198	3.9924	16	356	0.909	LARGE FOR M3815M S OF BORDER	1	34.84064591	-106.98342892
19	318658.29	3857171.98	1535.88	0.67	0.320	16.8804	17	3	0.980	BOMB, 7 M SOUTH OF BORDER	1	34.84070866	-106.98329563
20	318669.12	3857174.00	1535.11	1.62	0.142	1.4926	23	164	0.885	DEEP M38	2	34.84072887	-106.98317770

3.4.4 Area Remediated

Targets were remediated in the two airborne areas mentioned above, the Vehicular Area and the Primary Area. The coordinates of these areas are listed in Table 9 and their relative location is shown in Figure 13. A limited number of targets were also remediated at sites S2 and S7 in support of an earlier Oak Ridge survey of those sites. Their approximate location is shown in Figure 14.

Table 9. Coordinates for the Corners of the Two Remediation Areas at S1

Point	Latitude	Longitude	Northing (m)	Easting (m)
			NAD 83	
Vehicle-NW	34° 51' 18.912"N	106° 59' 05.400"W	3,858,788.00	318,549.62
Vehicle -NE	34° 51' 19.038"N	106° 58' 55.650"W	3,858,786.99	318,797.32
Vehicle -SE	34° 50' 26.694"N	106° 58' 56.400"W	3,857,174.63	318,746.38
Vehicle -SW	34° 50' 26.940"N	106° 59' 06.294"W	3,857,187.19	318,495.20
Primary-NW	34° 51' 41.071"N	106° 59' 27.914"W	3,859,482.06	317,991.39
Primary -NE	34° 51' 41.420"N	106° 59' 06.552"W	3,859,482.06	318,534.10
Primary -SE	34° 51' 08.891"N	106° 59' 05.770"W	3,858,479.46	318,534.10
Primary -SW	34° 51' 08.542"N	106° 59' 27.130"W	3,858,479.46	317,991.39

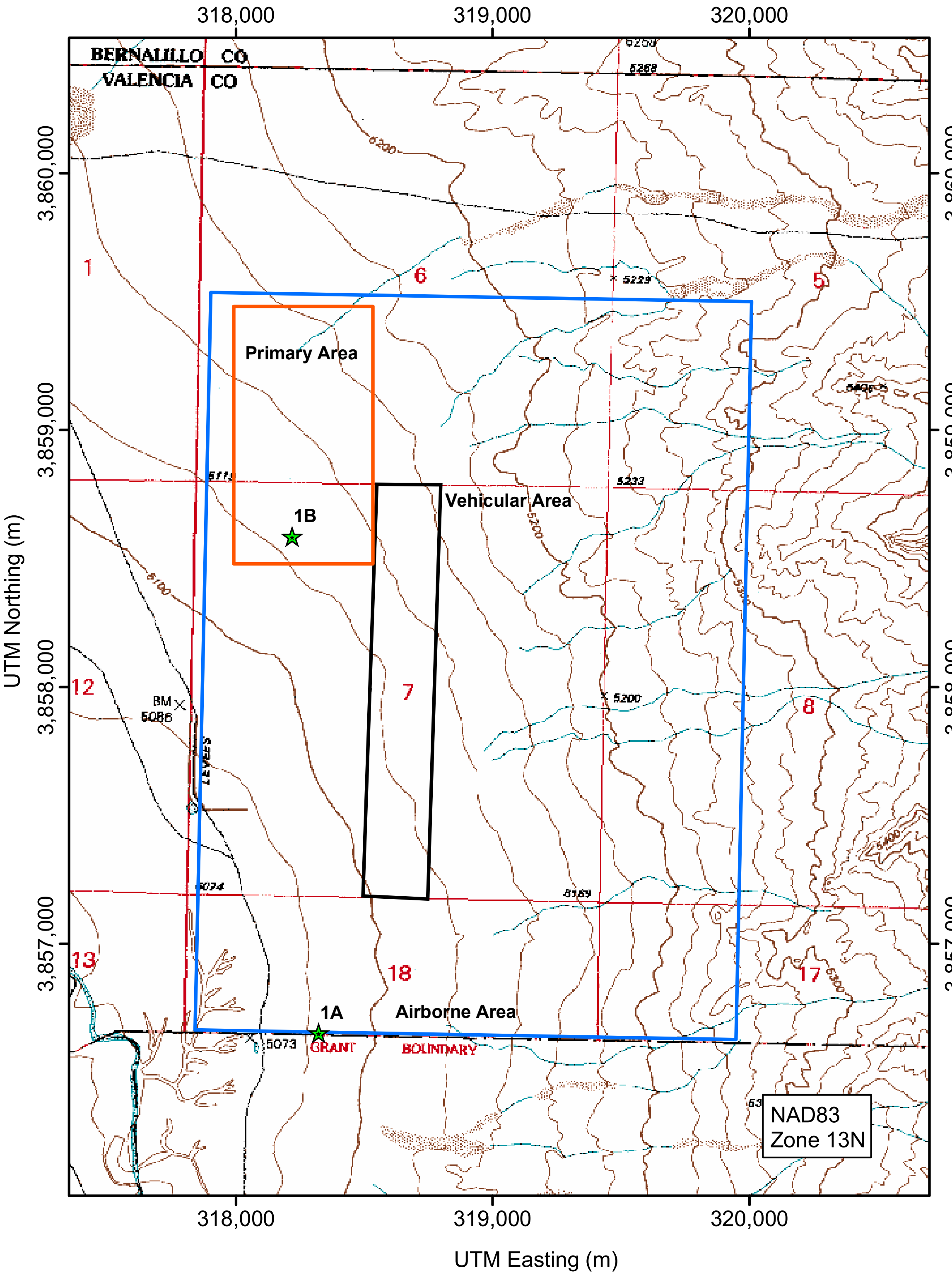

Fig. 13 – Relative location of the two remediation areas at the S1 site

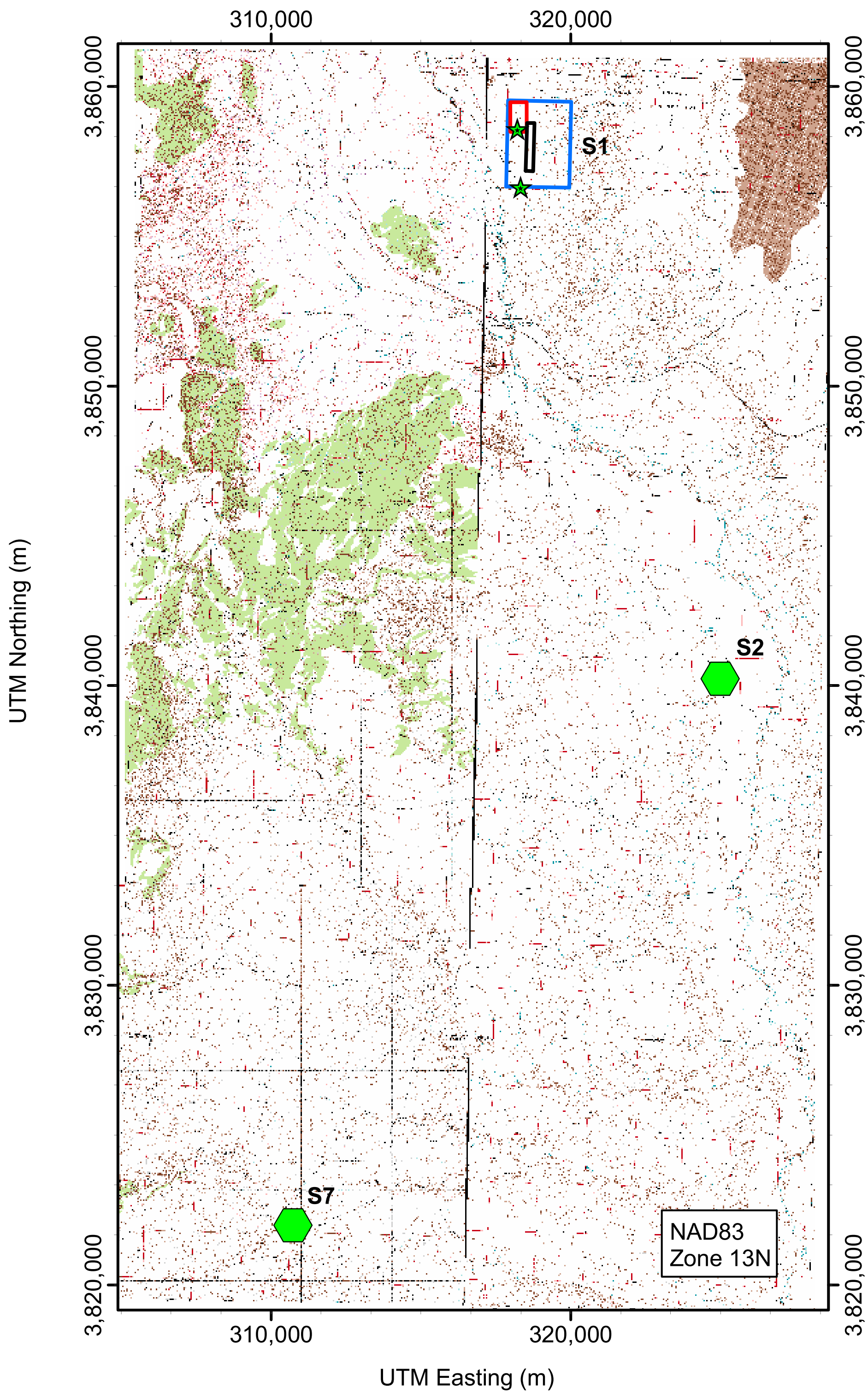

Fig. 14 – Map of the region showing the location of targets S2 and S7 relative to S1

3.4.5 Demobilization

At the conclusion of the survey, all MTADS equipment was returned to Blossom Point in the rented 53’ trailer by a government contract transportation firm. The helicopter used for the airborne portion of the survey was ferried back to its base in Baltimore, MD by the charter company, Helicopter Transport Services.

The remediated targets that were judged to be dangerous by the UXO crews were blown in place. All other remediation scrap was marked as inert and removed by a commercial scrap hauler under contract to EOTI, Inc.

4. Performance Assessment

4.1 Performance Criteria

Table 10. Performance Criteria for this Demonstration

Performance Criterion	**Description**	**Primary or Secondary**
Probability of Detection (P_d)	Fraction of emplaced targets detected by the technology.	Primary
False Alarm Rate (ha^{-1})	Number of anomalies per hectare not corresponding to ordnance items or ordnance-related material.	Primary
Location Accuracy	Mean miss distance for successfully detected targets	Primary
Production Rate	Area surveyed per day (or hour) for each technology	Primary
Ease of Use	A minimum of four people is required to conduct an airborne MTADS survey with an additional analyst in the field, or at home, to complete target analysis. They include a site/project supervisor, a pilot, a data acquisition operator, and a data preprocessor. While the position of project supervisor and data acquisition operator do not strictly require advanced training, we have found that the decision and diagnostic skills of more highly-trained scientists and engineers result in project efficiencies that more than compensate for the added personnel cost. At the present stage of development, the data preprocessor and analyst must be experts. As we gain more experience with the methods and refine the default assumptions we expect this requirement to relax. Vehicular surveys are typically conducted with a team of three NRL personnel, a site/project supervisor who assist with data preprocessing, a vehicle operator, and an on-site data analyst. The data flow is slower with the vehicular system so one less analyst is required. In addition to these positions, we typically employ two or three (two in this case) local field hands to assist with vehicle guidance, maintenance, and operation.	Secondary

Performance Criterion	Description	Primary or Secondary
Maintenance	The maintenance required for MTADS is typical of that required by computers and peripherals, laboratory and field electronics, and for transportation vehicles. Maintenance Manuals and preventive maintenance procedures have been established for all MTADS subsystems. Electronic and mechanical repair equipment and tool sets are packaged for transport to all demonstration sites. A list of critical spare components is maintained, as are materials for anticipated maintenance and repairs (vehicle service, cable repairs, computer change-out, etc). We encountered an unusual need during this survey, fiberglass repair. We are not equipped to handle this in the field so we truncated the survey and repaired the damage at home.	Secondary

4.2 Performance Confirmation Methods

Performance of each of the two systems was measured in two ways. First, each system surveyed the portion of the site in which the ESTCP Program Office arranged for a variety of inert ordnance to be seeded. After analysis of the survey data, we submitted two target lists to the Institute for Defense Analyses (IDA) for scoring. Using the known positions of these emplaced targets, IDA was able to determine the detection performance of each of the systems for the emplaced items, the number of false alarms, and the location accuracy for the detected items.

Additionally, 690 (711 original picks - 21 inadvertently included seed targets) targets were selected by IDA and the ESTCP Program Office for remediation by UXO technicians from EOTI, Inc., our remediation contractor. Each of the remediated items was characterized, photographed, and located by GPS re-survey. From these data, qualitative conclusions can be drawn about each systems detection performance and a quantitative measure of location accuracy derived. Each of these two sets of targets are discussed separately in the following section.

4.3 Data Analysis, Interpretation, and Evaluation

4.3.1 Emplaced Targets

The most instructive view of the performance of the two systems comes when considering the emplaced targets. The ESTCP Program Office arranged for 126 inert UXO items to be emplaced, 42 105-mm projectiles, 16 2.75-in warheads, 24 60-mm mortars, and 44 81-mm mortars. The location of four of each ordnance class was given to the demonstrators before the survey, these served as calibration targets. Not all of these targets are appropriate for each of the platforms. The airborne system is able to detect the mortars only under the most favorable noise conditions. Any statistics on detection of these items by the airborne system is more a measure of the site noise than the sensitivity of the system.

The detection performance and false alarm rate of the vehicular system with respect to these targets are detailed in Table 11.

Table 11. Measured performance against the emplaced targets for the vehicular system

Priority	Alarm rate (ha^{-1})*	Pd(overall)		P_d(105)	P_d(81)	P_d(60)	P_d(2.75)
		1.0 m	1.5 m	1.5 m	1.5 m	1.5 m	1.5 m
1	1	0.43	0.43				
2	3	0.68	0.68				
3	7	0.89	0.89				
4	12	0.94	0.94				
5	15	0.96	0.96				
6	16	0.96	0.96	0.94	0.95	1.0	1.0

*number of picks per hectare not corresponding to emplaced items (cumulative).

IDA analysts calculated the probability of detection using both 1.0 and 1.5-m detection radii. As expected from our past measures of location accuracy, the performance of the vehicular system was independent of this choice. The actual location performance of the vehicular system is given in Table 12 which shows no significant bias but a standard deviation slightly larger than we would have expected.

Table 12. Location performance of the vehicular system against the emplaced targets

	Δ Easting	Δ Northing
Mean (cm)	-1	4
Std Dev (cm)	12	13

It is interesting to note that the vehicular system failed to detect one of the emplaced 105-mm projectiles and one of the 2.75-in warheads, nominally the easier targets to detect. A detail of a small portion of the vehicular survey data that explains these missed detections is shown in Figure 15. A portion of one survey line, which coincidentally contains the two missed targets, is missing. This is a common occurrence and usually stems from poor GPS fit quality for a few seconds to minutes. The vehicular data analyst flags these missing lines for resurvey, which is usually accomplished at the end of the day while the field crew is securing the site for the evening. This missing line was marked as described but the sensor platform failure occurred before the resurvey occurred.

This performance is likely typical of real-world survey conditions where small data gaps are unavoidable due to deep ravines, trees, large bushes, etc. It unfortunately demonstrates the difficulties associated with a declaration that a site is completely clean.

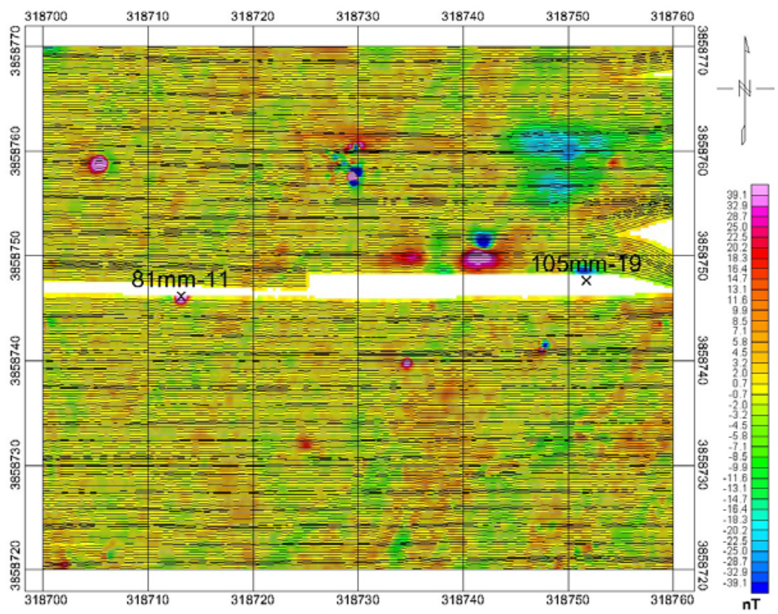

Fig. 15 – A small portion of survey data from the vehicular system showing a short segment of missing data that contains two of the emplaced targets

The performance of the airborne system to these same targets is detailed in Table 13. As was the case with the vehicular system, there is a negligible difference between the results using a 1.0-m detection radius and 1.5 m. We have demonstrated previously that our target location accuracy approaches 0.5 m so this is not unexpected. The actual location accuracy is given in Table 14.

Also not surprising is the detection probability for 60-mm mortars. As mentioned above, these targets are below the detection threshold of the airborne system except in the quietest environments. A calculation of detection performance without considering the 60-mms is given in Table 15.

Table 13. Measured performance against the emplaced targets for the airborne system

Priority	Alarm rate (ha^{-1})*	Pd(overall)		P_d(105)	P_d(81)	P_d(60)	P_d(2.75)
		1.0 m	1.5 m	1.5 m	1.5 m	1.5 m	1.5 m
1	2	0.21	0.21				
2	4	0.38	0.39				
3	7	0.51	0.54				
4	7	0.52	0.54				
5	9	0.53	0.55				
6	11	0.54	0.56	0.73	0.48	0.20	0.91

*number of picks per hectare not corresponding to emplaced items (cumulative).

Table 14. Location performance of the airborne system against the emplaced targets

	Δ Easting	Δ Northing
Mean (cm)	-4	4
Std Dev (cm)	31	30

Table 15. Measured performance for the airborne system excluding the 60mm mortars

Priority	Alarm rate (ha^{-1})*	Pd(overall)	
		1.0 m	1.5 m
1	2	0.26	0.26
2	4	0.45	0.46
3	7	0.59	0.61
4	7	0.60	0.62
5	9	0.61	0.63
6	11	0.62	0.64

*number of picks per hectare not corresponding to emplaced items (cumulative).

Even without the mortars, the airborne system failed to correctly report 13 of the 105mm and 2.75in targets. Detail of the analysis of these targets is given in Table 16.

Table 16. Detail of the larger targets not reported by the airborne system

Target ID	Weak Response	Signal Overlap	Analysis Error	Comments
105mm-02			x	North of Survey Area
105mm-03			x	North of Survey Area
105mm-06		x		Target lost in geology
105mm-07			x	4nT signal, not picked
105mm-12		x		Target lost in geology
105mm-16	x			No measurable signal
105mm-21			x	1.51-m position error
105mm-25			x	

Target ID	Weak Response	Signal Overlap	Analysis Error	Comments
105mm-28	x			Single track 6 nT peak signal
105mm-37	x			Target lost in geology
105mm-39		x		Target lost in geology
2.75in-02	x			Sensors 4.1m AGL
2.75in-04	x			No measurable signal

The detection data for both systems are shown plotted in a ROC curve in figure 16. Both systems exhibit reasonable classification performance as the bulk of the detections (93% for the vehicular system and 95% for the airborne) occur in the first three priority groups, high-confidence ordnance, medium-confidence ordnance, and low-confidence ordnance. Most of the ordnance targets categorized in the lower three groups are the result of remenant magnetization of these targets as illustrated for a vehicular anomaly in Figure 17. Although there is recent evidence that using the presence of significant remenant magnetization may not be justified,[18] it is a standard practice and was used by both analysis teams.

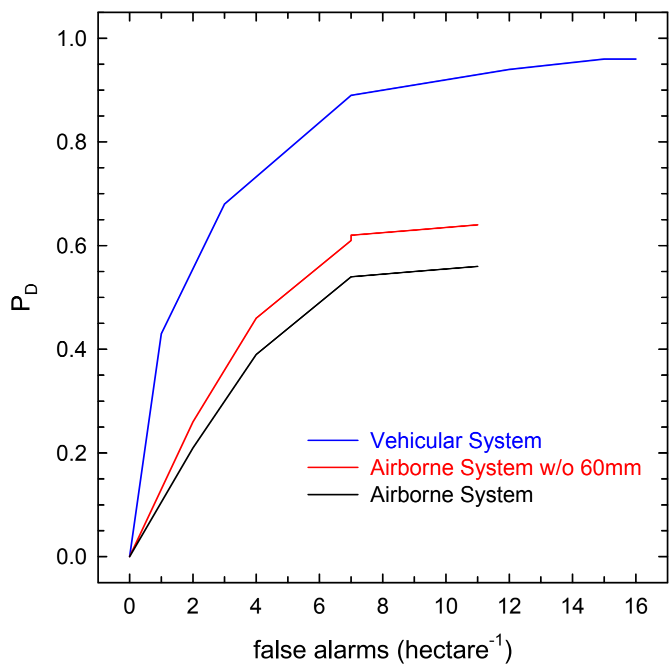

Fig. 16 – Detection data for the emplaced targets for both systems plotted as an ROC curve

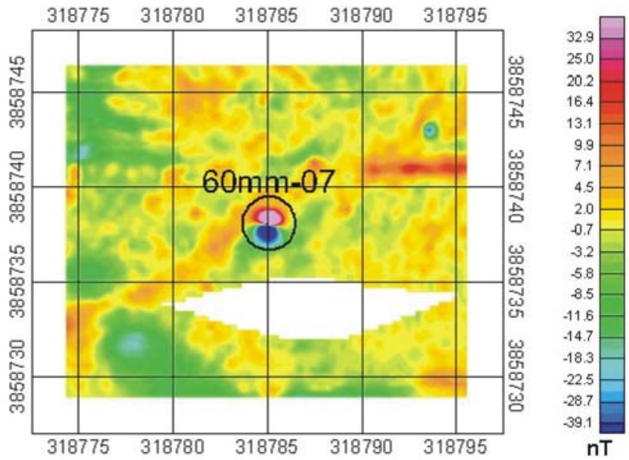

Fig. 17 – Example of an emplaced target with significant remenant magnetization that was misprioritized in the vehicular analysis

4.3.2 Remediated Targets in the Vehicular Area

Of the 371 targets in the vehicular area submitted to the remediation contractor for investigation, 338 were actually dug. A large majority of the remaining 33 targets were skipped for resource allocation reasons. At the end of the first week of remediation, we realized that targets below 5 feet deep were consuming an inordinate fraction of the remediation resources available. In order to maximize the number of targets remediated, and thus maximize the amount of comparison ground truth, we moved the remaining deep targets to the bottom of the dig priority list. The handful of missed targets that were not deep were missed due to clerical errors by the remediation teams (target removed but dig sheet not filled out, numbers transposed in the target reports, targets incorrectly checked off on the dig list, etc.). The dig list for the vehicular area with full remediation details is included in Appendix D with the missed targets highlighted.

Just as in the case of the emplaced targets, we can examine the performance of both systems with regard to the targets remediated in the vehicular area. Figure 18 shows the location performance of the two systems plotted on a polar plot. The vehicular data are shown in the left panel as blue symbols and the airborne data are in the right panel as red symbols. The outer radius shown in the plots corresponds to the 1.5-m halo used by IDA for their analysis. As in the case of the emplaced targets, a large majority of the target picks for both systems is within the more restrictive 1.0-m halo. The vehicular system displays a tighter clustering around the measured location of the remediated targets due to the higher data density of the vehicular anomaly maps and may have a slight bias to the northwest. The airborne data appear to be symmetrically clustered around the measured positions with most of the reported positions inside a 0.5-m radius.

Greater detail on the radial miss distance is given in Table 17 and illustrated in Figure 19. The location performance against these targets is very close to that measured against the emplaced targets.

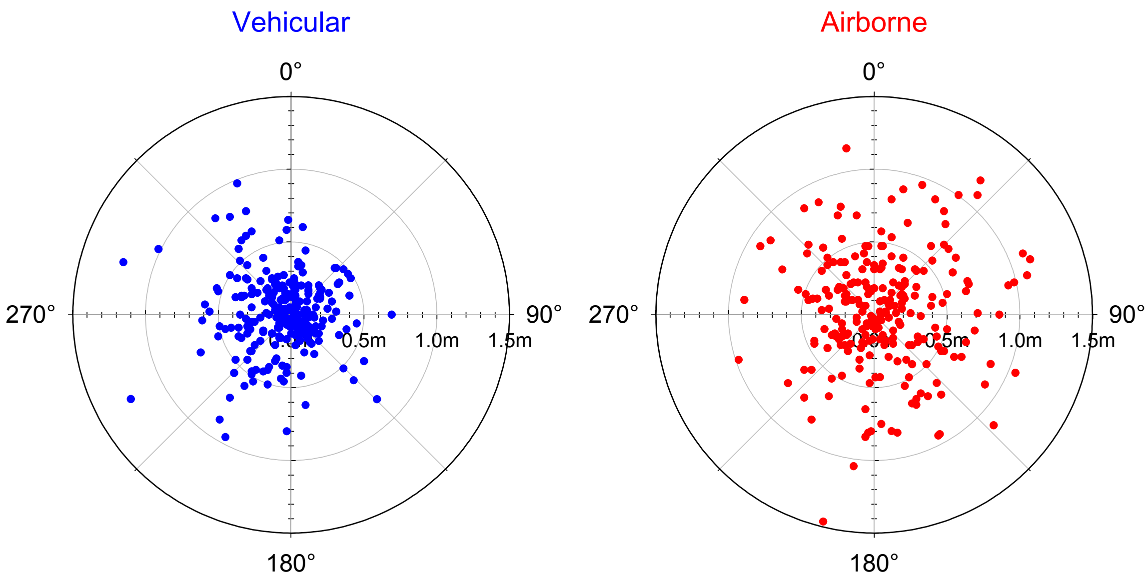

Fig. 18 – Location performance of the two systems for the remediated targets in the vehicular area. The vehicular data are shown on the left as blue symbols and the airborne data are on the right as red symbols.

Table 17. Detail of the location performance of the two systems against the remediated targets in the vehicular area.

System	Mean Miss Distance	90% Within	95% Within
Vehicular	35 cm	59 cm	77 cm
Airborne	49 cm	90 cm	108 cm

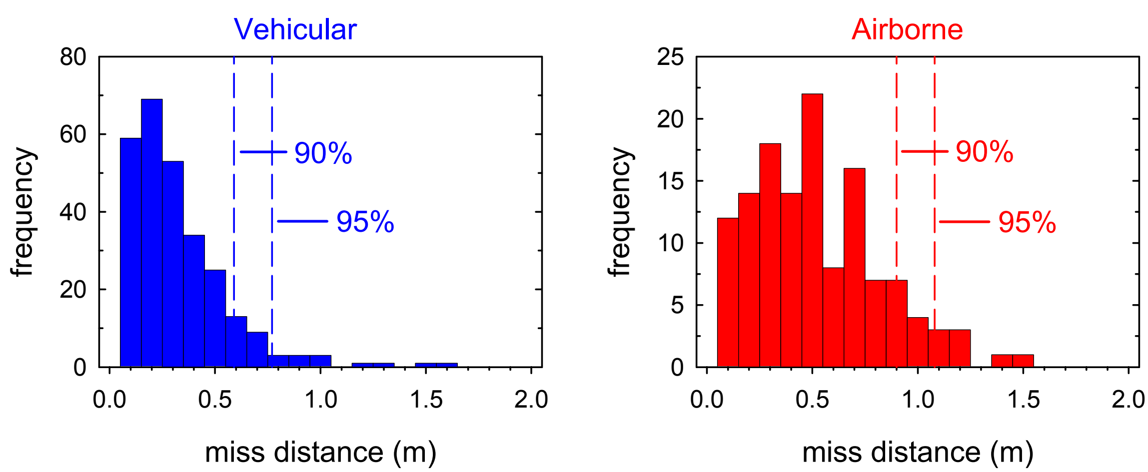

Fig. 19 – Comparison of the location accuracy of the two systems for the remediated targets in the vehicular area. The vehicular data are plotted on the left and the airborne on the right.

Again, as in the case of the emplace targets, a large fraction of the remediated targets that corresponded to ordnance and ordnance-related fragments and scrap were categorized in the first three priority groups. This is shown graphically in Figure 20 where the cumulative fraction of ordnance related targets is plotted against the priority group number.

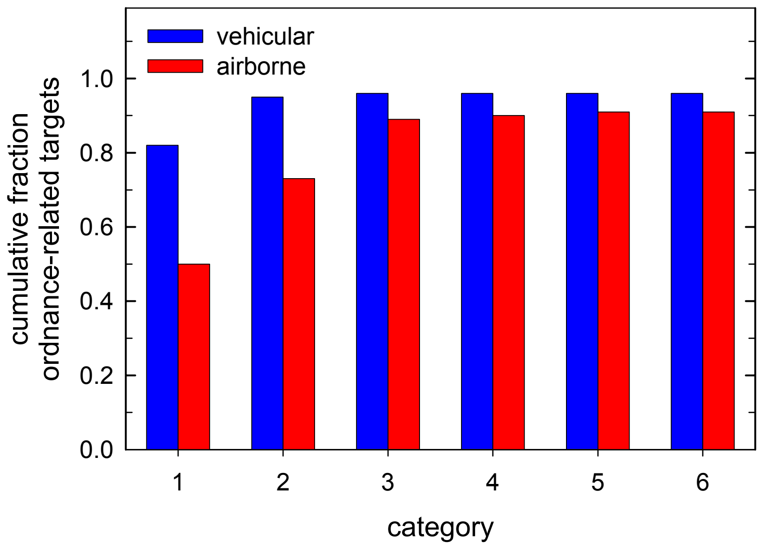

Fig. 20 – Cumulative fraction of ordnance-related remediated targets on the vehicular site by priority category for the two systems

4.3.3 Remediated Targets in the Primary Area

Of the 319 targets selected for remediation in the primary area, all but one were investigated. The one missed target was listed as 15.9 feet deep and was skipped due to the extreme cost of remediation. A dig list for this area with complete remediation results is included in Appendix E. The striking feature of this remediation was the substantial number of targets for which no metal object was found by the remediation team. These targets are listed in the remediation results as “no find” or “negative find.”

Since empty holes were not a problem in the vehicular area, the ESTCP Program Office asked each of the airborne teams to submit a list of twenty of these “no finds” that they would like to have re-investigated. Members of the vehicular MTADS team returned to the site during the third week in January 2004 to reinvestigate the selected targets.

4.3.4 Reinvestigation of “No Finds” in the Primary Area

Each of the two airborne analysis teams (NRL and ORNL) chose 20 targets from the list of “no finds” for reinvestigation and an additional 10 as backups. On January 18th 2004, two members of the vehicular MTADS team redeployed to target S1 to reinvestigate the selected targets using

the MTADS man-portable magnetometer system with two members of the remediation team arriving the next day. The details of this reinvestigation are given in Table 18.

Table 18. Details of the Man-Portable Survey

Date	Activity	Survey Base Names
Sun, Jan 18th	MTADS personnel arrive in Albuquerque.	
Mon, Jan 19th	Pick up MTADS equipment. Meet and brief Isleta Environmental Office, Assemble equipment and survey first ten targets.	04019003 thru 04019012
Tue, Jan 20th	Mark first ten remediation locations. Survey second ten targets. Work day cut short by afternoon rain Remediate first ten targets.	04020001 thru 04020010
Wed, Jan 21st	Mark next ten remediation locations. Survey sixteen additional targets. Mark ten additional remediation locations. Remediate fifteen targets.	04021001 thru 04021014 04021016 04021017
Thurs, Jan 22nd	Survey eleven targets. Mark last five remediation locations. Remediate ten targets. Fill and level all holes. Clean area of stakes and flagging.	04022001 thru 04022011
Fri, Jan 23rd	Return Borrowed GPS equipment and rental vehicles. MTADS personnel depart Albuquerque. Survey scrap certified and removed from the site.	
Sat, Jan 24th	Remediated targets perforated by the remediation team.	

Each target to be reinvestigated was reacquired using first-order point S1A for the GPS base station as in the original MTADS surveys and remediation. The first target in the target list was

point S1B to check the reliability of our GPS set-up. This point was reacquired within 5 cm each morning before surveying began. After acquisition of the targets, they were marked with paint, a wooden stake, and survey flagging.

Using a web template, a 5 x 5-m area was marked around each target aligned roughly N-S. An MTADS man-portable survey was performed within this area as shown in Figure 21. The man-portable sensors are spaced 25-cm apart and survey lines were 50-cm apart. The resulting survey data was processed as described above for the vehicular data and dig decisions made for each cell depending on the survey results. In total, 47 cells were surveyed (comprising the original forty targets plus ten from the extra lists; three of the cells contained two targets) and 35 were marked for remediation. The results of these analyses are summarized in Table 19 and the details of the analysis and remediation are given in Appendix F. Of the targets investigated, we would categorize three as original remediation error. Target 53, a BDU-33 at 4.5 feet, was clearly missed in the original remediation. Targets 56 and 61 were originally marked "no find" but we discovered fence wire mixed with the spoil dirt of the original hole. Several other targets corresponded to surface wire (particularly pin flag wire). Give the number of cattle on the site and the elapsed time since the original survey, no conclusion can be drawn on these targets.

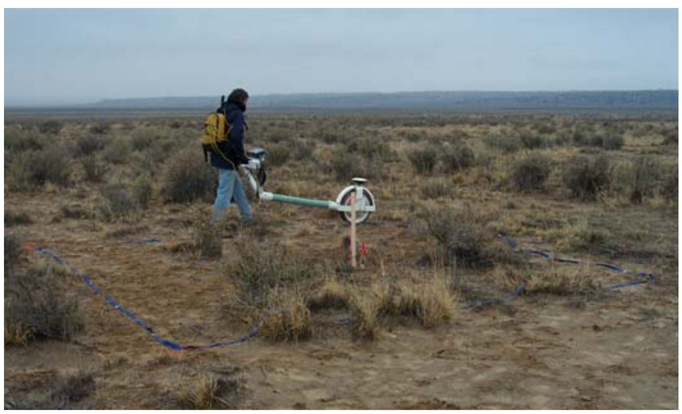

Fig. 21 – Man-portable survey of the targets being reinvestigated. The survey cell is marked by the 5 x 5-m web template.

Table 19. Summary of January 2004 Remediation of Previous "No Finds."

	No Man-Portable Anomaly	**No Find**	**Wire (comm., fence, or barbed)**	**Hot Rocks/Soil**	**Ferrous Metal**
Number	12	17	8	9	6

4.3.5 Remediated Targets at S2 and S7

Fifty targets were remediated at each of the two auxiliary targets based on earlier survey results from Oak Ridge National Lab. The dig lists are included in Appendix G.

5. Cost Assessment

5.1 Cost Tracking

Table 20. Itemized Costs for the Combined Vehicular and Airborne Surveys

Cost Category	Sub-Category	Cost	Sub-Total
Start-Up Costs			**$89,800**
	Preliminary Site Visit	$8,000	
	Test Plan Preparation	$15,000	
	Equipment Prep and Packing/Unpacking	$8,000	
	Rental Trailer and Transportation	$13,500	
	Analysts Set-up	$12,500	
	Travel for 5 Personnel	$5,000	
	Helicopter Mobilization	$27,800	
Logistics			**$24,200**
	Establish GPS Control Points	$14,600	
	Office, Garage Trailers and Portable Toilets	$2,350	
	Generator/Fuel/Electrician	$4,000	
	Materials	$3,250	
Operating Costs			**$82,900**
	Supervisor	$12,650	
	On-site Analysts	$18,000	
	Helicopter Back Seat Operator	$7,700	
	Per Diem	$4,000	
	Rental Vehicles	$3,500	
	Helicopter and Pilot Expenses	$20,000	
	Jet A Fuel	$2,900	
	Field Labor	$5,250	
	Equipment Repair	$8,900	
Analysis & Reporting			**$49,500**
	Target Lists, Dig Sheets, Final Report	$49,500	
Remediation			**$153,500**
Total Costs			**$399,900**

5.2 Cost Analysis

The cost of the combined vehicular and airborne survey of this area was $175/acre. Part of the reason for this relatively high per acre cost is the fact that the start-up costs, which were higher than normal due to the bad weather encountered by the aircraft during both halves of the mobilization, were only amortized over 1408 acres ($65/acre). On a larger area, the start-up and reporting costs could be spread wider easily bringing the per acre cost below $150. Even though there was complete overlap between the areas covered by the two systems this is still a reasonable guide for a live site survey where there will be regions, like the eastern edge of this site, where the airborne system cannot effectively survey and must be covered by the ground system. We recently completed just such a combined survey at the Badlands Bombing Range Impact Area[16] where the per acre cost was just below $100 because of favorable weather, site conditions, and logistics requirements.

6. Implementation Issues

6.1 End-User Issues

The primary end-users of this technology will likely be site managers of DoD ranges and bases. Although the equipment would be operated by a remediation contractor, no individual contractor has, so far, been able to make a business case for investing in this technology given the uncertain DoD funding environment. The start-up costs for a commercial version of the MTADS airborne system are approximately $400K (over half of which is devoted to the sensors and sensor electronics). Until a reliable funding stream is in place, the best option for transition of the technology is through a process where the NRL equipment is offered to a successful bidder as GFE on a range contract. This will allow the contractor to gain familiarity with operation, advantages, and disadvantages of the system.

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8. Points of Contact

Anne Andrews	ESTCP 901 North Stuart Street Suite 303 Arlington, VA 22203	Tel: 703-696-3826 Fax: 703-696-2114 Anne.andrews@osd.mil	Program Manager, UXO
Jeffrey Fairbanks	HydroGeologic, Inc. 1155 Herndon Parkway Suite 900 Herndon, VA 20170	Tel: 703-736-4514 Fax: 703-471-4180 jef@hgl.com	Program Assistant, UXO
H. H. Nelson	Naval Research Lab Code 6110 Washington, DC 20375	Tel: 202-767-3686 Fax: 202-404-8119 Cell: 202-215-4844 Herb.nelson@nrl.navy.mil	Principal Investigator
David Wright	AETC, Inc. 120 Quade Dr. Cary, NC 27513	Tel: 919-653-0215 x103 Fax: 919-653-0219 Cell: 919-332-3712 dwright@nc.aetc.com	Airborne Data Acquisition
J. R. McDonald	AETC, Inc. 120 Quade Dr. Cary, NC 27513	Tel: 919-653-0215 x102 Fax: 919-653-0219 jmcdonald@nc.aetc.com	Airborne Analyst
Nagi Khadr	AETC, Inc. 1225 Jeff Davis Highway Suite 800 Arlington, VA 22202	Tel: 703-413-0500 Fax: 703-413-0505 nagi@va.aetc.com	Airborne Analyst
Tom Furuya	AETC, Inc. 120 Quade Dr. Cary, NC 27513	Tel: 919-653-0215 x104 Fax: 919-653-0219 Cell: 919-264-7820 tfuruya@nc.aetc.com	Vehicular Analyst
Russell Jeffries	Nova Research, Inc. 1900 Elkin St. Suite 230 Alexandria, VA 22308	Tel: 703-360-3900 Fax: 703-360-3911 Page: 703-518-1950 rjeffr@erols.com	Logistics Support
Dan Steinhurst	Nova Research, Inc. Code 6110 Naval Research Lab Washington, DC 20375	Tel: 202-767-3556 Fax: 202-404-8119 Cell: 703-850-5217 dan.steinhurst@nrl.navy.mil	Vehicular Analyst

Jim Piatt	Pueblo of Isleta 1100 Broadway, SE Bldg. L Albuquerque, NM 87105	Tel: 505-869-5748 Fax: 505-869-4236 poienvir@nm.net	Director, Environment Department
Wayne Lewallan	EOTI 185 Rumson Road Rumson, NJ 07760	Tel: 732-345-8099 Fax: 732-345-7399 Cell: 732-492-1124 eoti@exit109.com	Senior UXO Supervisor